BELLCOMM, INC.

SUBJECT: AES Flight Mechanics and Performance Capabilities (U) Case 218

DATE: June 10, 1965

FROM: R. Y. Pei

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ABSTRACT

The flight mechanics and performance capabilities of Apollo Extension Systems missions are reviewed.

Present AES ground rules do not cover trajectory design. Strict adherence to Apollo Operational Nominal Trajectory Ground Rules* will preclude a majority of these missions. Judicious modifications of these ground rules, however, appear to be possible without seriously degrading the mission reliability. Such modifications would render feasible all AES missions that are currently being considered.

Payloads have then been estimated for each mission and the corresponding flight plans considered. Saturn IB launch vehicles are used for low altitude earth orbital missions that require no plane change capability. Saturn V launch vehicles are required for all other missions.

Finally the flight profiles are investigated in light of their concomitant environments and operating requirements, that would provide a basis for meaningful trade-offs in mission planning. Recommendations are also made for future efforts in these areas.

Author

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MEMORANDUM FOR FILE

1.0 Introduction

The purpose of this memorandum is to present data and analyses in the areas of astrodynamics and propulsion, that govern the flight performances of Apollo Extension Systems missions. For the sake of clarity, this material will be organized along the divisions of the various mission classes which have been proposed and it will be presented wherever possible in tabulated and/or graphical form. The preparation has drawn freely from various sources of information, as listed in the Reference section at the end of this memorandum. In this sense, it is a sequel to Reference 1. A significant portion of these references results from studies conducted at MSC, MSFC, and TRW/Space Technology Laboratories. The STL study effort has been made under a contract funded by NASA Headquarters. To these as well as many others who have made valuable contributions in the form of advice and discussion, indebtedness is gratefully acknowledged.

1.1 Mission Attributes

AES missions can be most conveniently grouped into four classes as summarized in Table 1, on the following page. Depending on the performance requirements, either the Sa-IB or the Sa-V launch vehicle may be considered. The following section lists the more important specifications of these launch vehicles, that have first order effects on the mission performance capabilities.

[redacted]

1.2 Launch Vehicles

The Sa-IB and S-V are respectively two and three-staged launch vehicles. In the latter case, a two-stage version may be considered for reasons to be pointed out later. Estimated performance capabilities are based upon the following payloads guaranteed by MSFC.

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TABLE 1

Mission Class	Mission Attributes
Earth Orbital	Duration 14-45 Days
Low Altitude No Plane Change	200 NM Inclination a Function of Launch Site and Launch Azimuth
Low Altitude Substantial Plane Change	200 NM High Inclination
Synchronous	Synchronous Altitude with or without Plane Change
Lunar Orbital	Duration Up to 38 Days (28 Days plus Transit Time)
Low Inclination	Near Equatorial
High Inclination	Lunar Polar Orbit
Lunar Exploration	Duration Up to 26 Days (14 Days plus Transit Time)
Apollo - Like	Continuous Abort Capability
Advanced	Restricted Abort Mode
Composite and Advanced	
Manned	Composite Earth Orbital, Lunar Libration Orbital, etc.
Unmanned	Planetary, Low Thrust, etc.

1.2.1 Saturn IB Launch Vehicle

The Saturn IB launch vehicle is capable of placing a 36,500 pound payload into a 105 nautical mile earth orbit with a 72° launch azimuth. It consists of two propulsive stages (S-IB and S-IVB) and the Instrument Unit. The S-IVB stage, as presently designed for the Saturn IB, has a one burn capability.

1.2.2 Saturn V Launch Vehicle

The Saturn V launch vehicle is capable of placing 240,000 pounds in earth orbit, and 95,000 pounds into a translunar trajectory. The standard Saturn V launch vehicle consists of three stages (S-IC, S-II and S-IVB) and the Instrument Unit. The S-IC stage will propel the launch vehicle to an altitude of approximately 33.3 NM and velocity of approximately 9,000 fps. After separation the S-II stage will continue to accelerate the vehicle to approximately 22,200 fps and lift it to an altitude of roughly 100 NM. The S-IVB stage, as presently designed for the Apollo mission, will permit one re-start to inject the payload from an earth parking orbit into the translunar orbit. The structural design of this third stage imposes a stack limit of approximately 110,000 pounds.

1.3 Spacecraft Propulsion

The Service Propulsion System (SPS) has an average static thrust rating of 21,900 pounds and is gimballed to provide thrust vector control. It has a nominal fuel capacity of 41,000 pounds and weighs 10,000 pounds when dry. The rocket engine is non-throttleable. The Command and Service Module (CSM) Reaction Control System (RCS) consists of individual units that are capable of developing 93 to 100 pounds of thrust. The total number of re-starts is nominally 5,500 with a life of 500 seconds. The same may be increased to 10,000 and 770 seconds respectively.

The Lunar Excursion Module (LEM) propulsion characteristics are summarized as follows:

	Descent Stage	Ascent Stage
Thrust	10,500 lbs.	3,500 lbs.
Propellant Weight	18,000 lbs.	4,922 lbs.
Specific Impulse	305 secs.	305 secs.
Throttling Range	10 - 1	None

[redacted]

1.4 Mission Constraints

Present AES ground rules do not impose specific constraints on trajectory design. AES propulsion systems, however, are currently subject to the following ground rule; viz:

There shall be no uprating of propulsion systems except through normal improvement in the course of the basic (Apollo) program.

Reference 1 contains estimates of performance capabilities that reflect this constraint, as well as a tentative guideline, adopted so as to provide a better definition of the problem in the course of analysis. This guideline is as follows:

The shaping and selection of trajectories and orbits should be carried out with as much flexibility as is consistent with mission requirements and crew safety. Apollo trajectory ground rules will be followed where applicable. Departures from these will be permitted if they are necessary for the execution of a particular mission and if total mission assurance and crew safety are not seriously impaired. Furthermore, modifications of the ground rules and supplementary guidelines will be considered if significant benefits may accrue with respect to the overall objectives of the AES program. Such modifications and guidelines may arise in different areas. The following are possible examples.

1.4.1 It has been shown (Reference 2) that if free return trajectories are used for lunar landing missions, the lunar area which is accessible is severely limited. In order to extend this area of accessibility for lunar exploration, this constraint may have to be relaxed.

1.4.2 Apollo ground rules call for two passes over the landing site area with the CSM-LEM before initiating the LEM descent. Similarly, the duration of the transearth lunar parking orbit phase is also kept to approximately the same length. It has been shown (Reference 3) that lengthening of these orbit stay times will greatly improve the accessibility of the lunar surface.

1.4.3 The Apollo ground rule that limits the total mission duration to 14 days or less is obviously not acceptable for extended lunar exploration missions, since surface stay times of about two weeks may be desired. To permit these longer stay times, the total mission duration time must increase.

1.4.4 The problem of abort is an important consideration in any manned space flight mission, and a continuous abort capability is certainly desirable. For the Apollo mission, the short surface stay time renders it possible to satisfy this requirement. Such may not be the case for longer surface stay time, particularly if it is desirable to reach an extensive area of the moon. A similar situation arises in some lunar orbital missions.

1.4.5 Apollo ground rules impose severe restrictions on the launch geometry. Such restrictions will be reflected in the payloads, particularly those for the earth orbital missions under consideration. Relaxations of such ground rules, in keeping with fundamental range safety constraints may be indicated.

2.0 Mission Description

In this section will be presented some typical flight modes, profiles, and estimated payloads. As mentioned in Section 1, Saturn IB and Saturn V launch vehicles will be used without uprating, and the payload estimates are derived from the base performance capabilities contained therein.

2.1 Earth Orbital Missions

Table 2 summarizes the orbital capabilities and flight profiles used in this study. Various combinations of the propulsion capabilities available in the Saturn IB, the two-stage and three-stage versions of the Saturn V, and the Apollo Service Propulsion System (SPS) are indicated for achieving the specified orbits. For 45-day-near-earth orbital missions, a nominal altitude of 200 NM was selected in view of the satellite lifetime requirement (See Section 3.3).

It is to be emphasized that these represent only some possible flight modes. There are undoubtedly many other modes that will permit achievement of specified orbits with comparable payloads. Estimates of the latter have been based on information cited above, and impulsive velocity changes have been adopted for succeeding phases after a "first orbital" insertion (See section 3.1). While a conscious effort has been made to maximize payload, no overall optimization has been carried out. (See section 4).

MISSION CLASS*	Earth Orbital Low Altitude No Plane Change	Earth Orbital Low Altitude No Plane Change	Earth Orbital Low Altitude Substantial Plane Change	Earth Orbital Synchronous	Earth Orbital Low Altitude Substantial Plane Change	Earth Orbital Low Altitude No Plane Change
LAUNCH VEHICLES	Sa-IB	Sa-IB	Sa-V	Sa-V	Sa-V	Sa-V
MISSION ORBITAL REQUIREMENTS ALTITUDE (NM) INCLINATION (DEG.)	200 28.5	200 50	200 90	19350 0	200 -83.5	200 28.5
LAUNCH GEOMETRY LAUNCH AZIMUTH (DEG.) POWERED FLIGHT OPERATIONS	90 2 STAGES TO PARKING ORBIT	44 2 STAGES TO PARKING ORBIT	108.5 YAW STEERING DURING 2nd & 3rd STAGES	90 3 STAGES TO PARKING ORBIT	108.5 YAW STEERING DURING 2nd & 3rd STAGES	90 2 STAGES TO FINAL ORBIT
PARKING ORBIT ALTITUDE (NM) INCLINATION (DEG.)	80 28.5	80 50	100 90	100 28.5	100 -83.5	
TRANSFER ORBIT INJECTION BY PERIGEE ALT. (NM) APOGEE ALT. (NM)	SPS 80 200	SPS 80 200	S-IVB 100 200	S-IVB 100 19350	S-IVB 100 200	NONE
EARTH ORBIT INSERTION BY MAX. EST. WEIGHT IN ORBIT (LBS.)	SPS 33670	SPS 32175	S-IVB 106495	S-IVB & SPS 57250	S-IVB 106495	S-II 220000

SPS - SPACECRAFT SERVICE PROPULSION SYSTEM
*REFER TO SECTION 1.1

TABLE 2
EARTH ORBITAL MISSIONS

2.2 Lunar Orbital Mission

Two types of lunar orbital missions are considered. They will be characterized by their orbital inclination with respect to the lunar equatorial plane. A description of these missions follows.

2.2.1 Low Inclination Lunar Orbital Missions

This class of mission is perhaps more useful for site certification purpose. In order to obtain sufficient data regarding candidate Apollo landing sites and navigational land mark locations, a low inclination lunar orbit has been shown to be adequate (Reference 4). A typical flight mode would resemble that of the Apollo mission with the exception that there will be no lunar landing and take-off phases. The sequence of major events is as follows:

Earth Launch:	Same as Apollo
Earth Parking Orbit:	Near circular 95-100 NM Altitude
Insertion	Same as Apollo
Coast	Same as Apollo
Translunar Phase:	
Injection	First or Second Orbit
Transposition & Docking	Same as Apollo
Return Mode	Unrestricted
Flight Time	Up to 110 hrs.
Pericynthion	25 NM

Lunar Parking Orbit:

Deboost during hyperbolic approach
Parking Orbit insertion
Perform Orbital mission & corrective plane changes as needed

Transearth Phase	
Injection	Same as Apollo
Flight Time	Up to 110 hrs.
Re-Entry	Same as Apollo

A reasonable estimate of the lunar orbiting payload may be obtained upon augmenting the Apollo CSM by the LEM weight, or approximately 30,000 pounds, resulting in a total initial weight in orbit of about 55,000 pounds.

2.2.2 High Inclination Lunar Orbital Mission

This class of mission is perhaps most useful for scientific survey purposes. In order to realize maximum coverage of the lunar surface, a polar orbit is desirable. It is possible for the lunar approach trajectory to enter into a polar orbital plane by selecting the suitable entry point at the moon's sphere of influence. A polar inclination, plus the orbital stay time, will, however, rotate the orbital plane such that an earth return may not be always possible within the Apollo spacecraft capability.

The flight profile can be similar to that for the low inclination orbit. The lunar orbit duration could be as long as a lunar month or 28 days in order to observe the moon through a cycle. Orbiting payload will be sensitive to mission requirements, particularly abort considerations (See Section 3.6). For preliminary mission planning purposes, it is assumed that excluding provisions for continuous abort capability, the velocity requirements are approximately similar for both lunar orbital missions. Consequently, similar estimates for the orbiting payload may be used.

2.3 Lunar Exploration Missions

An extensive exploration of the moon may be accomplished by satisfying two criteria: (1) permit landings at a maximum number of possible sites on the moon, and (2) permit longer surface stay times. Such extended surface missions may consist of a lunar flight to deliver an unmanned Shelter to the lunar surface, to be followed by another flight to execute a manned lunar landing and subsequent surface operations. Depending on the contingency requirements, this class of missions may result in different performance capabilities. These are summarized as follows.

2.3.1 Apollo-Like Missions

The earlier missions should perhaps be designed with a high degree of contingency provisions, and it might be desirable to retain the Apollo ground rule of continuous abort capability. In this case, the flight profile may be identical to that for the Apollo, resulting in similar weight estimates. An exception would be that in the case of the LEM/Shelter mission, there will be no lunar launch and ascent transfer phase, and that the LEM-Shelter landing will be entirely unmanned. The bases for weight estimates are:

	LEM/Shelter Mission	LEM/Taxi Mission
CSM	Same as Apollo	Same as Apollo
LEM A. S.	Available for pay-load to be delivered	Same as Apollo
LEM D. S.	Same as Apollo	Same as Apollo

The accessible area will be restricted to below 10 degrees latitude for stay time up to 14 days (See Section 3.5) because of the desire for continuous abort.

2.3.2 Advanced Lunar Exploration Missions

Accumulated experience derived from earlier flights might perhaps enable later lunar exploration missions to be planned with relaxed ground rules concerning abort from the moon. For planning purposes, bases for weight estimates should remain unchanged for reasons to be discussed later. Areas of accessibility, on the other hand, will undergo significant improvment (See Section 3.6). The flight profile will be substantially the same as that of the Apollo mission, except perhaps for possible relaxations in the flight time, and the specifications for the lunar parking orbit phase (See Section 3).

3.0 Performance Analysis

The objective of this section is to investigate the several AES mission flight profiles, in light of their concomitant environments and operating requirements, that would provide a basis for meaningful trade-offs in mission planning. Ten major areas have been identified as of primary importance in their interaction with the flight profiles as well as their effect of the AES mission objectives. These areas are:

Range Safety Considerations

Boil-off Problems

Satellite Lifetimes

Synchronous Mission Capability

Lunar Surface Accessibility

Abort Considerations

Lighting Constraints

Survey and Mapping Coverage

Long Duration Perturbations

Composite Missions

These will now be discussed individually.

3.1 Range Safety Considerations

For a given orbit, the launch vehicle performance capability is extremely sensitive to the launch geometry. This is particularly true in the case of achieving a given earth orbit, since range safety and related considerations may impose severe constraints on allowable launch geometry. For a detailed discussion of range-safety and related considerations and their interactions with the launch geometries, reference is made to Appendix I.

In general, large characteristic velocities are required to execute substantial plane changes, if required, at orbital speeds. This will drastically reduce payload capabilities. However, fundamental range safety constraints may permit relaxation of Apollo ground rules such that suitable yaw and three dimensional maneuvering programs may be designed to accomplish plane changes more economically at lower vehicle velocities.

3.2 Satellite Lifetimes

The predicted satellite lifetime is a function of the orbital altitude, the satellite ballistic number and the atmospheric model used. Since the AES missions are timed for a period that may include a year of maximum solar activity,

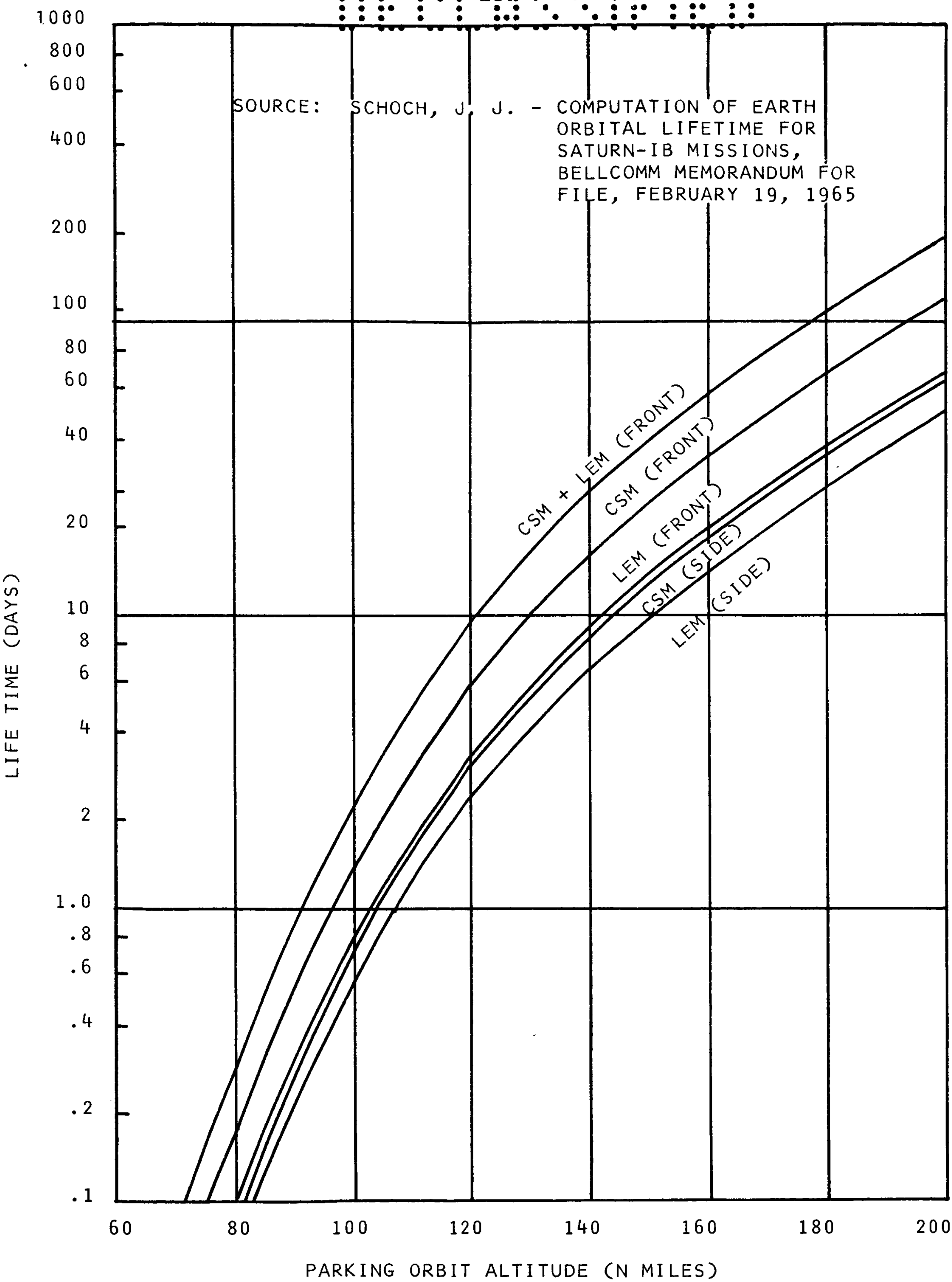

FIGURE 1 - LIFE TIME OF CSM AND LEM FOR SIB CIRCULAR ORBITS

estimates based on predicted atmospheric model for extremely high solar activity at diurnal maximum should be used as guidlines. The orbital lifetimes of Apollo spacecrafts have been computed based on such a conservative atmosphere model, and it is indicated that for mission duration of about 45 days, a nominal altitude of 200 NM should be adequate (Reference 5). The integrated lifetime curve is included in Figure 1.

3.3 Synchronous Mission Capability

The performance capability of the Sa-V launch vehicle for the earth synchronous orbital mission depends to a large extent upon the restart capability of the S-IVB stage. In order to restart this stage, the pressurization system must have the capability to repressurize the partially depleted tanks of propellants. This problem is further aggravated by the boil-off of cryogenic propellants during the fairly extended period of transfer to synchronous altitude. With helium heaters placed on the S-IVB stage, as are now on the S-IV stage, the problems associated with the multiple start of the S-IVB stage could be eliminated.

3.4 Boil-Off Problems*

On Saturn V missions where there is a relatively long coast period for the S-IVB between burns, the boil-off of liquid hydrogen becomes appreciable and results in a significant reduction of its capability. For synchronous orbital flights the boil-off is greater because of the longer coast between burns on the Hohmann transfer ellipse, and the slightly greater boil-off rate due to longer continuous periods of sunlight.

There are two methods which have been suggested for reducing the boil-off. By choosing launch dates close to the earth's equinoxes, one can choose a Hohmann transfer ellipse such that the apogee lies at the far edge of the shadow of the earth. Thus a major portion of the time during the transfer would be spent in this shadow. This, in addition to reducing the time spent in parking orbit before transfer, can significantly reduce the heat transfer to the propellant. However, this method would limit the launch timing to a function of the desired synchronous ground track point.

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*This section has been contributed by Mr. P. W. Conrad.

A second method to reduce boil-off involves a modification of the S-IVB stage. By the use of high performance insulations the heat transfer to the propellant may be reduced to one-eighth that of the unmodified stage. The boil-off reduction is estimated below for a nominal Apollo mission:

MODE	STANDARD Sa-IVB	SUPER INSULATED Sa-IVB
Ground Hold Boil-Off	220 lbs.	26.4 lbs.
Boost Boil-Off	570 lbs.	70.5 lbs.
In Orbit Boil-Off	3820 lbs.	501.7 lbs.

This type of insulation can take only small aerodynamic and structural loads and thus requires a jettisonable shroud during boost. This increase in stage weight is offset somewhat by the possible reduction of internal insulation caused by this modification. The gain resulting from this modification is roughly one pound of payload in either syncronous orbit or translunar trajectory for every pound of boil-off reduction. For the synchronous missions of interest, addition of insulation could apparently result in a payload increase of about 4,000 lbs.

With this provision, the following is feasible. After a due east launch, the first two stages followed by the first burn of the S-IVB stage place the satellite in a 100 NM parking orbit. After about 1-1/4 orbits during which the systems are checked out, the S-IVB stage is restarted at the descending node to execute a Hohmann transfer to synchronous altitude with a partial plane change. Arriving at the apogee which is the synchronous altitude, the S-IVB stage is started once more to place the satellite in a new elliptic orbit with a higher apogee velocity. After one orbit, during which the expended S-IVB stage is jettisoned, and the transposition and docking of CSM and LAB module accomplished, the Service Propulsion System engine is ignited to complete the plane change and circularization maneuver.

3.5 Lunar Surface Accessibility

Lunar surface accessibility for an AES lunar landing mission is a problem which is now under study. It is affected by such constraints as the earth-moon trajectory return mode and the LEM-CSM rendezvous capability, as well as the surface stay time and abort contingency requirements. In general, the orientation of the arrival and departure velocities at the moon are related geometrically through the lunar surface stay time by virtue of the moon's rotation. Furthermore, these orientations remain substantially constant for a given set of launch and terminal conditions and flight time. The choice of CSM lunar parking orbit, to permit the successful execution of a LOR type mission, is further constrained by the limited plane change capability during descent to and ascent from the lunar surface. References 3 and 7 investigate the effect of such parameters on lunar surface accessibility. It appears that relaxation of Apollo ground rule requiring continuous abort is almost mandatory if any substantial extension of surface accessibility is to be achieved with Apollo systems.

3.6 Abort Mode Considerations

For low inclination lunar orbital mission, it might be possible to execute an in-plane return injection during each revolution of the parking orbit. This is due to the fact that the orbital inclination is low and orbital stay time may not be excessive.

For high inclination lunar orbital missions, however, this is no longer the case with the proposed flight mode. The abort capability of the spacecraft depends to a large extent upon the transearth return time as well as the availability of alternate propulsion modes (Reference 8). It has been shown that through the use of the LEM descent stage for lunar orbit insertion, a lunar polar orbital payload capability of about 35,350 lbs can be achieved while still satisfying the continuous abort requirement.

For lunar surface missions, relaxation of abort rules is less likely to affect the payload deliverable to the surface. This is essentially due to the fact that with the LEM descent stage unmodified, weight landed on lunar surface will be consistent with Apollo capability. In the case of the LEM-taxi mission, however, trade-off possibilities may exist between CSM and LEM ascent stage capabilities, to permit some gains, if contingency requirements were reduced.

3.7 Lighting Constraints

Lighting constraints for lunar orbital missions are still in the process of being defined. The ability of a lunar orbital mission to fulfill the objective of a mapping or survey mission is maximized by suitable sun angles. At any given instant, there is an annular ring about the sub-solar point, of good lighting conditions. The width of this annular ring is a function of the photographic requirements which in turn depend on the tasks of the particular mission in question. The detailed design of the mission is influenced by the width of the acceptable lighting band and its interaction with the motion of this band due to the earth's motion and to gravitational precessional terms. The concept of using nodal regression to compensate for the displacement of the sub-solar point is being explored.

3.8 Survey and Mapping Coverage

This aspect of lunar orbital mission is obviously closely related to the lighting constraints. The latter will have to be defined before any assessment of various orbital methods available for adequate coverage of regions of interest can be made. Also, regions of interest may require further definition. Near polar regions are poorly illuminated at all times, thus limiting coverages.

3.9 Long Duration Perturbations

AES missions are, in general, characterized by their relatively long mission durations. Perturbations of orbital elements may be important and their effects on overall mission performance may have to be investigated.

3.10 Composite Missions

Certain composite missions may be of interest. Possible examples are:

a. The orbiting CSM of a LEM/Shelter or LEM/taxi mission may perform some lunar orbital survey objectives.

b. A low altitude high inclination earth orbital mission may be used to incorporate one of the proposed AES experiments viz,: an Echo fly-by maneuver.

c. An earth synchronous orbital mission may be used for another AES experiment, viz,: the capture of Syncom.

d. Other classes of missions may be of interest and should be investigated. Some examples are: libration orbital missions where the spacecraft may appear to be stationary with respect to the earth-moon system; earth-moon periodic orbit, where the spacecraft may circumnavigate the moon and the earth or may enter into an orbit in cislunar space; etc.

4.0 Conclusions

Increases in performance capability beyond the Apollo mission without uprating Apollo propulsion systems are usually made at the expense of reliability or upon the expectation that experience gained in Apollo will reduce or eliminate contingency requirements. Present AES ground rules, however, do not cover trajectory design. The following remarks are, therefore tentatively made in this light.

4.1 Earth Orbital Missions

Only synchronous missions and S-IB missions are payload limited. For these missions, payload optimization may be a useful criterion. It is conceivable, however, that other criteria such as launch windows, mission flexibility, etc., may take precedence, where the mission is not payload limited. Under these circumstances, other flight modes than those proposed should be investigated. In general, it appears that the performance capability of AES earth orbital missions is reasonably adequate, except perhaps for synchronous missions.

4.2 Lunar Orbital Missions

Lighting constraints and photographic requirements seem to constitute the governing factors in the design and shaping of trajectories. Alternate propulsion modes may affect significantly the abort capability and useful payload.

4.3 Lunar Exploration Missions

Relaxation of Apollo constraints and ground rules are necessary to conduct, in a trajectory sense, an extended stay lunar exploration mission with increased surface accessibility. Deliverable payload, however, is largely governed by LEM descent stage capability.

4.4 Recommendations

A review of AES studies in the area of flight mechanics and performance capabilities, indicate the following needs:

a. AES Trajectory Ground Rules

b. Further studies of propulsion problems affecting synchronous mission, e.g., S-IVB restart capability, boil-off problems, payload optimization, etc.

c. Reference trajectories for lunar orbital and surface missions.

d. ΔV Budgets

e. Trade-off analyses to evaluate alternate trajectories.

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Attachment:
Appendix I

Copy to
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APPENDIX I

RANGE SAFETY AND RELATED CONSIDERATIONS

1. Introduction

This section briefly summarizes launch site and range safety limitations as they affect the performance of earth orbital missions discussed under Section IV of this report.

2. Launch Geometry

In this attachment the launch geometry of a mission is distinguished from the flight profile at launch in that the latter is used to refer to a complete description of the powered flight between initial lift-off and insertion into the "first orbit". Launch geometry, on the other hand, contains only information, mostly geometric, that has first order effects on range safety and related considerations as well as performance capabilities. For planning purposes, the important factors that enter into the launch geometry are:

Launch azimuth
Dog-leg maneuvers
Yaw and general three dimensional maneuvers
Stages involved

The term "first orbit" used above signifies that it need not be the final orbit called for by the mission under consideration.

3. Range Safety and Related Requirements

There are two basically different aspects to the range safety and related problems. Firstly, the deterministic aspect is that which results from the launch geometry. Impact range, exit azimuth and ground track fall under this category. Secondly, the probabilistic aspect encompasses range safety problems owing to the uncertainties in guidance, rocket performance, etc. The dispersion ellipses associated with impact points are examples of this category.

Generally, the range safety and related requirements considered here may be described as the safety to persons and property. A derived form of this description may be expressed in terms of:

(a) Restrictions imposed on the ground track resulting from the launch geometry, and

(b) Restrictions imposed on the planned stage impact points.

An example of such fundamental range safety constraints would be that there shall be no overflight within 25 NM of the continental United States or Canada and that all planned stage impact points shall be in the open ocean area. Table III illustrates the payload sensitivity to launch geometry in the case of earth polar orbital mission.

4. Orbital Inclination and Launch Geometry

For a given orbital inclination greater than the launch site latitude, there is a particular azimuth that permits direct injection into the desired plane. However, the resultant ground track and planned stage impact points may not be acceptable. The launch geometries proposed in this study result from the following guidelines.

(a) The launch Azimuth is optimized with respect to the inclination to within the bounds set by the exit azimuth limits.

(b) If the orbital inclination cannot be attained by the above optimization, the required plane change is accomplished by means of yaw and general three-dimensional maneuvers, programmed to satisfy the fundamental range safety constraints.

It is to be noted that the required inclination is that of the "first orbit". In the case of the earth equatorial synchronous orbital missions, the chosen mode calls for a 28.5° inclined parking orbit to be followed by a Hohmann transfer to synchronous orbital altitude, with a plane change of 28.5° to be executed at the apogee. Accordingly, the first guideline mentioned above is sufficient, viz., a due east launch.

5. Conclusion

For a given earth orbital mission the performance capabilities are extremely sensitive to the launch geometry. This is due to the fact that large characteristic velocities are required to execute substantial plane changes, if required, at orbital speeds.

TABLE III: SATURN V EARTH POLAR ORBIT PERFORMANCE

Altitude	Range Safety Limit	Profile	Weight
100 NM	NASA 72°	2 Dimensional Direct Ascent, Plane Change with S-IVB	0
200 NM	" "	" " " " " " " " "	"
100 NM	" "	Intermediary elliptic orbit*	38,400
200 NM	" "	" " " " " " "*	37,000
100	AF 50°	2 Dimensional Direct Ascent, Plane Change with S-IVB	40,000
200	" "	" " " " " " " " "	38,000
200	" "	" " " " " " " " "	35,100 excluding LEM adapter
100	NASA 72°	Steer with S-II over populated areas	110,000***
200	NASA 72°	" " " " " " " " "	110,000***

* 2 dimensional direct ascent to desired altitude with first 2 stages.

Then S-IVB kicks into highly eccentric ellipse, and makes plane change at apogee. SPS is needed for circularization at perigee.

** SPS is used for part of the plane change.

*** S-V Stack Limit.

Source: Conrad, P. W. & Pei, R. Y. - Interim Report for AES Flight Mission Assignment: Part II Propulsion and Trajectory Capabilities, Bellcomm, Inc., TM-65-1011-1

By means of a suitable yaw and three dimensional maneuvering program, it is possible to accomplish plane changes more economically at lower vehicle velocities, while satisfying the fundamental range safety constraints. On the other hand, range safety and related considerations imposed constraints on the optimization and launch azimuth and subsequent ground track and planned stage impact points.

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DECLASSIFIED

Transmittal List for Bellcomm Documents

The following represents a checklist of accompanying Bellcomm technical documents being delivered to NASA/ATSS-10. Three copies of each of the 86 reports are included for a total of 258 documents.

Following each document listing is the Special Task Numbers (S-) or General Mission Numbers (G-) under which it was prepared together with the distribution category approved by NASA/MA-2.

See General Notes, page 9, for an explanation of the various general Missions, Special Tasks and types of technical documents.

Project Apollo - Additional Results Concerning Aircraft Deployment to Provide Coverage During the Injection Phase (MF-5-4332-4)
R. C. Peterson
Bell Telephone Laboratories, Inc.
(Unclassified)
January 15, 1965 S-15 B

Impact Response Characteristics and Associated Impact Attenuation Techniques for Lunar and Planetary Landing Vehicles (TM-65-1012-1)
R. K. McFarland
(Unclassified)
January 21, 1965 S-18 B

Monitoring Procedures and Landing Radar Requirements During Powered Descent Phase of the Lunar Excursion Module /U/ (TR-65-209-1)
W. G. Heffron
(CONFIDENTIAL)
January 22, 1965 S-9 B

Lunar Orbiter Mission, Planning /U/ (TR-65-211-1)
D. D. Lloyd, R. F. Fudali
(CONFIDENTIAL)
January 25, 1965 S-11 B

Atmospheric Correlation Effects in Range Rate Tracking (MF-5-4332-5)
G. H. Myers
Bell Telephone Laboratories, Inc.
(Unclassified)
January 28, 1965 S-14 B

Interim Report for AES Flight Mission Assignment Plan: Part I - Summary /U/ (TM-65-1011-7)
T. L. Powers
(CONFIDENTIAL)
January 29, 1965 S-18 B

Interim Report for AES Flight Mission Assignment Plan: Part II - Propulsion and Trajectory Capabilities (TM-65-1001-1)
P. W. Conrad, R. Y. Pei
(Unclassified)
January 29, 1965 S-18 B

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Interim Report for AES Flight Mission Assignment Plan: Part III - Extended CSM Spacecraft /U/ (TM-65-1011-2)
K. E. Martersteck
(CONFIDENTIAL)
January 29, 1965 S-18 B

Interim Report for AES Flight Mission Assignment Plan: Part IV - LEM Objectives /U/ (TM-65-1011-3)
J. E. Waldo
(CONFIDENTIAL)
January 29, 1965 S-18 B

Interim Report for AES Flight Mission Assignment Plan: Part V - Lunar Mission Objectives and Rationale (TM-65-1011-4)
N. W. Hinners
(Unclassified)
January 29, 1965 S-18 B

Interim Report for AES Flight Mission Assignment Plan: Part VI - Earth Orbital Mission Objectives and Rationale (TM-65-1011-5)
W. B. Thompson
(Unclassified)
January 29, 1965 S-18 B

Interim Report for AES Flight Mission Assignment Plan: Part VII - Scheduling Constraints and Alternative Schedules /U/ (TM-65-1011-6)
P. Gunther
(CONFIDENTIAL)
January 29, 1965 S-18 B

Interim Report for AES Flight Mission Assignment Plan: Part VIII - Launch Facilities and Equipment /U/ (TM-65-1033-1)
V. Muller, H. E. Stephens
(CONFIDENTIAL)
January 29, 1965 S-18 B

Bellcomm, Inc., Quarterly Progress Report (October, November, December 1964 (65-101-1)
(Unclassified)
January 29, 1965 G* B

Minutes of the Second Apollo Interface Coordinate Systems Meeting (Memo for file)
J. S. Dudek, J. O. Cappellari, R. L. Wagner
(Unclassified)
February 1, 1965 S-9 B

Saturn IB Test Mission for LEM Alone on SA-206 /U/ (Memo for File)
D. R. Valley
(CONFIDENTIAL)
February 1, 1965 S-17 B

Saturn IB/Apollo Payload Capability /U/ (Memo for File)
H. S. London
(CONFIDENTIAL)
February 2, 1965 G-3 B

A Review of the Readability Potential of the Mission Control Center Television Displays (MF-5-4332-7)
R. O. Wise
Bell Telephone Laboratories, Inc.
(Unclassified)
February 3, 1965 S-19 B

Statistical Variation in Performance of Rocket Engines and a Possible Method of Increasing Performance of the Saturn V Vehicle /U/ (TM-65-2011-1)
M. W. Cardullo, J. L. Current
(CONFIDENTIAL)
February 3, 1965 G-3 B

Unified S-Band Communications Margins Calculations for One-Way Links (TM-65-2021-1)
J. D. Hill, J. T. Raleigh, R. L. Selden
(Unclassified)
February 4, 1965 S-15 B

Use of Pure Oxygen in Spacecraft (Memo for File)
P. R. Knaff
(Unclassified)
February 8, 1965 G-2 B

Lunar Orbit Rendezvous Reference Trajectory Data Package Sensitivity Matrices for Apollo Error Analysis /U/ (STL #8408-6084-RC-000)
Space Technology Laboratories
(CONFIDENTIAL)
February 15, 1965 S-9 B

Lunar Surface Models (Memo for File)
R. F. Fudali
(Unclassified)
February 15, 1965 S-11 B

The Effect of Rocket Exhaust Gas Impingement on Various Surfaces (Memo for File)
N. W. Hinners
(Unclassified)
February 15, 1965 S-11 B

Project Apollo - Transmission Advantage of Horn Reflectors Relative to Cassegrain Antennas (Memo for File) (MF-5-4332-8)
E. J. Linger
Bell Telephone Laboratories, Inc.
(Unclassified)
February 16, 1965 S-15 B

Interim Report on Lunar Landing Dynamics Specific Engineering Studies (MM-65-2)
Bendix Products Aerospace Division
(Unclassified)
February 17, 1965 S-20 B

Computation of Earth Orbital Lifetimes for Saturn IB Missions /U/(Memo for File)
J. J. Schoch
(CONFIDENTIAL)
February 19, 1965 G-3 B

The Micrometeroid Environment of Project Apollo (TR-65-211-2)
J. S. Dohnanyi
(Unclassified)
February 25, 1965 S-11 D

On the Estimation of Reentry Shock Geometry (TM-65-1011-8)
J. S. Dohnanyi
(Unclassified)
February 25, 1965 S-11 C

Summary of Work Performed Under Bellcomm/NASA Task 11 (TR-65-211-3)
B. T. Howard, D. B. James, G. T. Orrok
(Unclassified)
February 26, 1965 S-11 B

Sensitivity Matrix Data for LEM Ascent to 50,000 Foot Orbit /U/ (Memo for File)
I. Bogner
(CONFIDENTIAL)
March 3, 1965 S-9 B

Saturn V/Apollo Hold and Recycle Capability (Memo for File)
C. Bidgood
(Unclassified)
March 4, 1965 S-24 B

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Communication Reliability for the Apollo Manned Space Flight Network (MSFN) Based on Past NASA Network Performance (TM-65-2021-2)
G. H. Speake
(Unclassified)
March 9, 1965 S-15 B

Procedure for Estimating the Undetected Error Rate for the RCA Data Transmission System (TM-65-1031-1)
J. S. Engel
(Unclassified)
March 9, 1965 S-21 B

Interim Report on Lunar Landing Systems Engineering Study (TR-65-220-1)
D. Macchia, J. Nutant
(Unclassified)
March 10, 1965 S-20 B

Design Philosophy of Modulation Indices for Apollo Unified S-Band Modes with Ranging (TM-65-2021-3)
J. D. Hill
(Unclassified)
March 11, 1965 S-15 B

Apollo Communications Capability From the Lunar Surface to the Manned Space Flight Network (Memo for File)
J. D. Hill, R. L. Selden
(Unclassified)
March 15, 1965 S-15 B

Unified S-Band Communications Margins During the Launch Phase of a Saturn V Apollo Mission (Memo for File)
J. D. Hill, R. L. Selden
(Unclassified)
March 16, 1965 S-15 B

Ranger VII Photo Analysis - Preliminary Measurements of Apollo Landing Hazards (TM-65-1012-2)
C. J. Byrne
(Unclassified)
March 17, 1965 S-11 B

Project Apollo - Communications Considerations for Aborts During Injection (Memo for File) (MF-5-4334-1)
R. Cerino
Bell Telephone Laboratories, Inc.
(Unclassified)
March 17, 1965 S-15 B

Apollo Saturn V Unified S-Band Communications and Tracking Coverage From Lift-off Through Insertion (Memo for File)
J. P. Maloy, H. Pinckernell
(Unclassified)
March 19, 1965 S-15 B

Laboratory Test Methods for Determining Readability of TV Displays (MF-5-4332-22)
R. O. Wise
Bell Telephone Laboratories, Inc.
(Unclassified)
March 22, 1965 S-19 B

Satellite Relay at VHF Between Aircraft and Manned Space Flight Network (Memo for File)
E. M. Coombs
(Unclassified)
March 29, 1965 S-15 B

Optimum Two Impulse Deboost into Lunar Orbit (TM-65-1011-9)
P. Gunther
(Unclassified)
March 31, 1965 S-18 B

Lunar Landing Site Accessibility for July, 1969 (TR-65-209-3)
V. S. Mummert
(Unclassified)
March 31, 1965 S-9 B

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Interim Report on Saturn V Hold Capability and Recycle Requirements (TM-65-1033-2)
C. H. Eley, A. W. Starkey,
H. E. Stephens
(Unclassified)
April 1, 1965 S-24 B

Summary of Requirements for Instrumentation Aircraft During the Injection Phase of the Apollo Lunar Landing Mission (Memo for File)
J. J. Hibbert
(Unclassified)
April 2, 1965 S-15 B

Project Apollo - Aircraft-Ground Communications Using 6,000 nm. Altitude Satellite Radio Relay (Memo for File) (MF-5-4334-8)
E. J. Linger, J. M. Trecker
Bell Telephone Laboratories, Inc.
(Unclassified)
April 2, 1965 S-15 B

Design Philosophy for the Frequency Modulated Modes of the Apollo Unified S-Band Communications System (TM-65-2021-5)
J. D. Hill
(Unclassified)
April 5, 1965 S-15 B

Advantages and Disadvantages of Using Only Unified S-Band Communications Systems in the Apollo Spacecraft (Memo for File)
R. L. Selden, A. G. Weygand
(Unclassified)
April 6, 1965 S-15 B

A Computer Program for Calculating Coverage of Space Vehicles During Powered Phases by Earth Based Communications Stations (Memo for File)
H. Pinckernell
(Unclassified)
April 8, 1965 S-15 B

Apollo MSFN Tracking Coverage During Sixteen Earth Revolutions at 105 nm. Altitude for Launch Azimuths at 72, 80, 90, 100, 108 Degrees (Memo for File)
J. P. Maloy
(Unclassified)
April 10, 1965 S-15 B

Status of CALIPS Pressure Switches for Saturn IB and Saturn V Launch Vehicles (Memo for File)
L. G. Miller
(Unclassified)
April 13, 1965 S-24 B

Lunar Soil Mechanics, Landing Dynamics and Apollo Site Survey (TR-65-2[illegible]-2)
N. W. Hinners
(Unclassified)
April 15, 1965 S-20 B

Preliminary Report on the Hold and Recycle Capability for the Apollo Spacecraft (TM-65-1032-1)
(Unclassified)
V. Muller
April 20, 1965 S-24 B

Degradation of Lunar Orbiter Capability due to Processor Web Sticking (Memo for File)
D. D. Lloyd
(Unclassified)
April 20, 1965 S-11 B

Summary of Apollo Interface Activity (Memo for File)
G. B. Troussoff
(Unclassified)
April 28, 1965 S-1 B

Digital Data Acquisition System (DDAS) for Saturn IB/V (Memo for File)
D. M. Duty
(Unclassified)
April 30, 1965 S-21 B

Documentation of Digital Computer Programs for Lunar Landing Dynamics Specific Systems Engineering Studies (MM-65-5)
Bendix Products Aerospace Division
(Unclassified)
May, 1965 S-20 B

Mobile Arming Tower (TM-65-1033-3)
A. W. Starkey
(Unclassified)
May 3, 1965 S-24 B

Summary of Communication Requirements for Apollo Missions (TM-65-2023-1)
J. E. Johnson, D. S. Kutch
(Unclassified)
May 6, 1965 S-14 B

Summary Review of the Martin Crew-Performance Studies (Memo for File)
B. H. Crane, P. R. Knaff
(Unclassified)
May 7, 1965 G-2 B

Summary of Apollo Requirements for Satellite Communications (Memo for File)
J. J. Hibbert
(Unclassified)
May 11, 1965 S-15 B

Apollo Injection Phase Tracking Accuracy with Range, Range Rate and Angles Measurements from a Single Tracker (Memo for File)
R. W. Friester
Bell Telephone Laboratories, Inc.
(Unclassified)
May 13, 1965 S-14 B

Summary of Launch Window Constraints for Apollo (Memo for File)
P. S. Schaenman
(Unclassified)
May 18, 1965 S-24 B

Saturn IB/V Data Link Evaluation (Progress Report No. 3) (TR-65-221-2)
E. L. Grumman
(Unclassified)
May 20, 1965 S-21 B

Comparison of Tracking and Communication Coverage During Apollo Saturn V Launch Into Earth Orbital Altitudes of 85 and 105 nm. (Memo for File)
J. P. Maloy
(Unclassified)
May 26, 1965 S-15 B

A Study of the Behavior of Lunar Accessibility Over Extended Time Periods Part I - Free Return Trajectories (TR-65-209-4)
J. O. Cappellari, W. D. Kinney, A. A. Satterlee, R. D. Tigner
(Unclassified)
May 28, 1965 S-9 B

Comparison of Alternate Implementation Schemes for S/V Damage Assessment by Visual Means (Memo for File)
P. R. Knaff
(Unclassified)
May 28, 1965 S-14 B

Free Return Lunar Accessibility Over Extended Time Periods (TR-65-209-5)
J. O. Cappellari, A. A. Satterlee, R. D. Tigner
(Unclassified)
May 28, 1965 S-9 B

Status and Schedule Monitoring of Apollo Software (TR-65-222-1)
W. M. Keese, et al
(Unclassified)
May 31, 1965 S-22 B

Bellcomm, Inc. Quarterly Progress Report (January, February, March 1965) (65-101-2)
(Unclassified)
May 31, 1965 G* B

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Final Report-Lunar Landing Dynamics Specific Systems Engineering Studies (Report No. MM-65-4)
Bendix Products Aerospace Division
(Unclassified)
June, 1965 S-20 B

Influence of Hold Capability and Recycle Requirements on Apollo/Saturn V Launches (TM-65-2032-1)
C. H. Eley, V. Muller,
H. E. Stephens
(Unclassified)
June 3, 1965 S-24 B

Command and Control from Launch to Insertion (Memo for File)
J. P. Downs, M. M. Purdy
P. E. Reynolds, P. F. Sennewald,
J. E. Volonte
(Unclassified)
June 8, 1965 S-14 B

Project Apollo - Aircraft-Ground Communication Using Synchronous-Orbit Satellite Radio Relay (Memo for File) (MF-5-4334-11)
E. J. Linger, J. M. Trecker
Bell Telephone Laboratories, Inc.
(Unclassified)
June 9, 1965 S-15 B

AES Flight Mechanics & Performance Capabilities /U/ (Memo for File)
R. Y. Pei
(CONFIDENTIAL)
June 10, 1965 S-18 B

Saturn IB Test Mission for LEM Alone on Saturn-Apollo 206 /U/ (Memo for File)
D. R. Valley
(CONFIDENTIAL)
June 11, 1965 S-17 B

Apollo Spacecraft Propulsion Performance Capabilities for Saturn V Lunar Missions and Simulations /U/ (Memo for File)
T. R. Kornreich
(CONFIDENTIAL)
June 14, 1965 S-17 B

Revised Weight Estimates for NASA AES and DOD Earth Orbit Missions (Memo for File)
J. E. Waldo
(Unclassified)
June 15, 1965 S-18 B

Computer Simulation of Flight Crew Operations in Apollo: The Nominal Mission (TM-65-2022-1)
R. J. Litschgi, M. A. Robinson
(Unclassified)
June 15, 1965 S-14 D

Project Apollo - Communications Processor-Analysis of Storage Function for Data Flow to the MOC/DSC (MF-5-4332-31)
R. M. Marella
Bell Telephone Laboratories, Inc.
(Unclassified)
June 16, 1965 S-19 B

The Effects of Ground Antenna Gimbal-Lock on Communication Coverage During Launch (Memo for File)
H. Pinckernell
(Unclassified)
June 24, 1965 S-15 B

A Computer Program for Calculating the Communications Performance of Some Phase Modulated Apollo Unified S-Band System Modes (Memo for File)
J. D. Hill
(Unclassified)
June 24, 1965 S-15 B

Lunar Soil Mechanics Information Derivable from Slope Analyses (Memo for File)
N. W. Hinners
(Unclassified)
June 25, 1965 S-9 B

The Effect of Rocket Exhaust-Gas Impingement on Various Surfaces (Memo for File)
N. W. Hinners
(Unclassified)
June 29, 1965 S-9 B

GENERAL NOTES

(1) *Indicates technical work performed under the General Mission and not identified by a designated General Mission number.

(2) General Missions (G-)
1 - Mission Planning and Mission Assurance
2 - Mission Operations, Including Human Factors and Communications
3 - Vehicle and Spacecraft Systems
4 - Launch Operations and Checkout
5 - Guidance Navigation

(3) Special Tasks (S-) (Short Titles)
1 - Apollo Program Specification
2 - Checkout and Launch from Lunar Surface
3 - Estimation of Computing Needs
4 - Characterization of Natural Environmental Hazards
5 - Development of Mission Assurance Program
6 - Communications and Tracking System Requirements and Planning
7 - Lunar Logistics
8 - Not Issued
9 - Apollo Trajectory Analysis
10 - Development of Checkout Program
11 - Evaluation of Natural Environmental Hazards
12 - Computer Operations
13 - Apollo Flight Test Plan
14 - Apollo Operations Planning and Analysis
15 - Requirements for and Evaluation of Apollo Communications
16 - Miscellaneous Short-Term Studies of Immediacy
17 - Apollo Flight Mission Assignments
18 - Operations and Exploration Planning
19 - Review of Acceptance Plans for IMCC Launch Data System and Launch Trajectory Data System
20 - Lunar Landing Dynamics
21 - Saturn IB/V Launch Vehicle Computer Controlled ESE System
22 - Management Procedures in Computer Programming for Apollo
23 - Not Issued
24 - MILA Operations and Equipment Review
25 - MSF Center Computer Operations Standardization
26 - Saturn IB/Centaur Systems Engineering

(4) Following is a list of definitions for the codes used in the various report numbers:

TR - Bellcomm Technical Report
TM - Bellcomm Technical Memorandum
MM - Bendix Products Aerospace Division Report
MF - Bell Telephone Laboratories Memorandum for File